

“ IoT enabled systems for monitoring the CNC machine towards Industry 4.0 ”

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How a CNC machine fails?[\[1\]](#) [\[4\]](#)

A healthy CNC machine can perform tasks quickly and accurately, but an unfunctional CNC machine can quickly turn into a white elephant. CNC machines only understand G-code, and they can't self-diagnose problems inside them, so we have to keep CNC operators and machinists around to guide them and check for malfunctions. CNC machines create heat, noise, vibration, debris, oil, and dust, so working next to one is dangerous.

There can be several reasons for malfunctions, including inappropriate use of the equipment (such as debris entering sensitive parts), tool breakage, loose grip on the work piece, tool deformation (melting) due to over-heating, or software error.

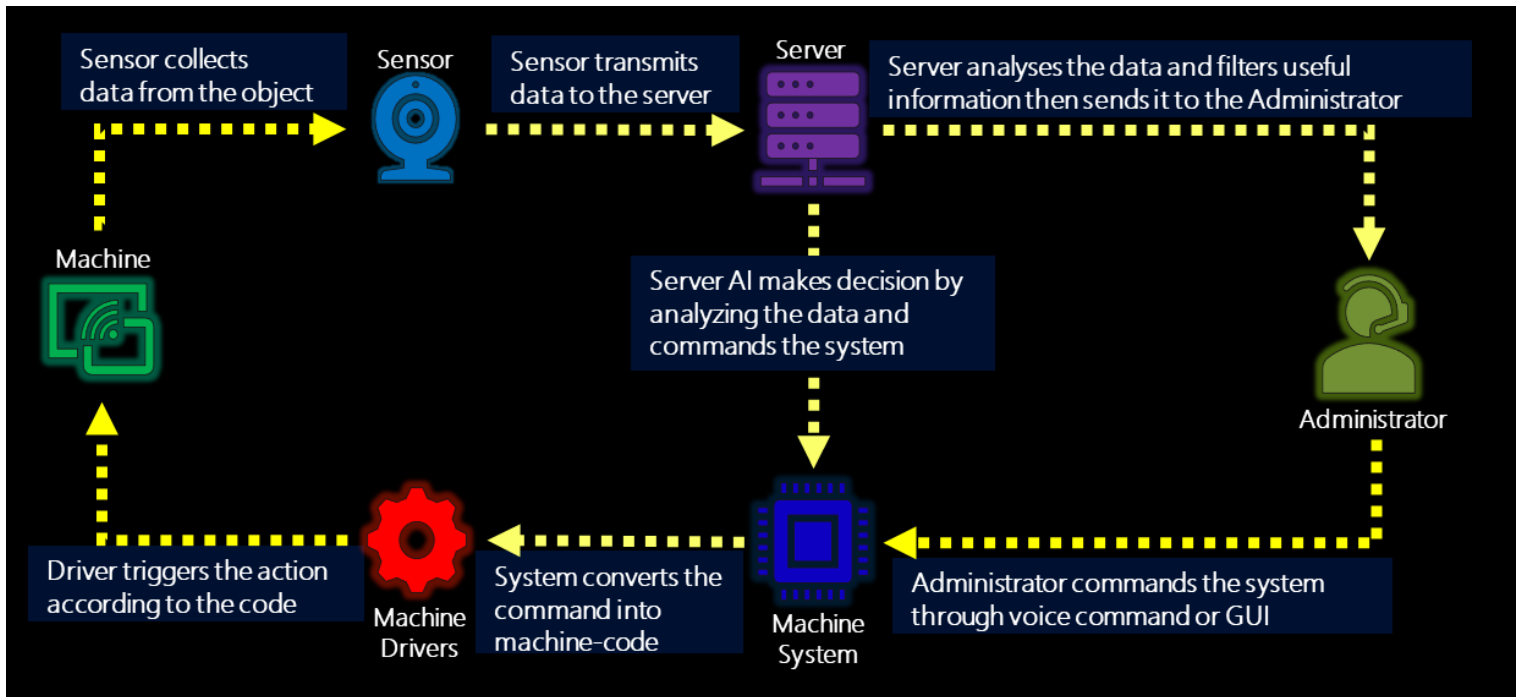
Solution : Internet Of Things :

Brief Introduction:

The Internet of Things (IoT) is a network of devices and objects that are connected to the internet. It consists of around 40 billion devices worldwide, all of which

are equipped with sensors. Examples of IoT devices include cars, phones, light bulbs, and smart home devices. IoT technology started with simple devices like toasters and garage door openers, and now even large companies are implementing IoT solutions to maximize efficiency and profitability.

Work-flow :



In order to improve overall accuracy, we can use multiple methods of monitoring to monitor the machines. We can place the server inside the control room and sensors inside the CNC machines.

Some advanced CNC machines come with built-in feedback systems, which provides sufficient information to monitor them. Therefore, we don't have to attach any extra sensors to them; we simply have to place a server to process the information and make actions based on that.

Collection Of Data And Server Response :

We can place a Piezoelectric Accelerometer^[2] on the tool to detect vibration patterns^[3]. We will first find the vibration patterns for a fully functional machine working on an identical product. If the tool fails or gets stuck, the patterns will be different, and the server will pause the machine. If vibration is too high, the server will decrease the tool spindle RPM.

We can use an audio sensor to measure the amplitude of various audio frequency bands of machine-sounds^[5]. We will train the server AI to detect abnormal sounds and to ignore outside noises. If a machine part breaks or gets stuck, a noise will be produced. This noise will create an interference in the normal sound and the server will detect it. It will stop the machine and report to the operator.

We can use infrared imaging technologies^{[6][7]} to detect the health of CNC machines, based on machine learning. We will first give the server the infrared data of the normally working machine, and then we will add the infrared data when different parts (i.e. a particular motor or spindle) are thermally malfunctioning. Based on these results, the algorithms will learn to identify which parts are overheated. We will also provide the solution (such as decreasing RPM or shutting down the machine) for each situation.

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With current technology there may be inconsistent results due to various coolant liquids flowing through the machine, so the cooling system may significantly alter the real results. So we will also provide the server data of the machine when various cooling systems are on.

We can attach some sensors to the tool turret or the spindle to get their states, like mini-gyroscopes to measure their tilt, and to measure their positions, we can use the same technique as is used in a laser based optical mouse^[8]. The sensor in the mouse takes

pictures at every millisecond and computes the change in position based on the variation in of patterns. We will configure it to measure the position of the turret in three-dimensional space. We will place sensors in all three axis motors to accomplish the same.

The server will calculate the deviation between the ideal state (input) and the real state (output), and it will notify the operator if the deviations are too significant. Furthermore, with sufficient data, the server can also then adjust the machine to bring the real state closer to the ideal state all by itself^[10].

We can use a circuit containing the galvanometer to check if the metal workpiece is in place. If the workpiece is not in place, no current can flow through the galvanometer. In that case, the machine will be stopped immediately. The wires will be placed on four base corners of the workpiece.

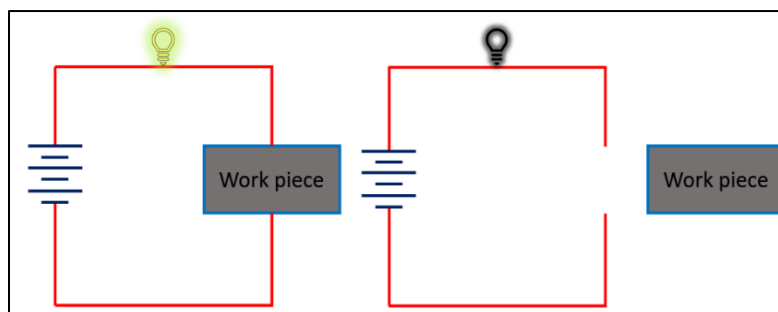


Figure 1

We can use the same circuit as above and attach one end to the tool and the other end to the workpiece to ascertain if the tool is in contact with the workpiece. The algorithm will verify the code to see if the tool is supposed to be in contact with the workpiece at a particular time. If the tool can contact the workpiece at inaccurate time or duration, it will notify the operator.

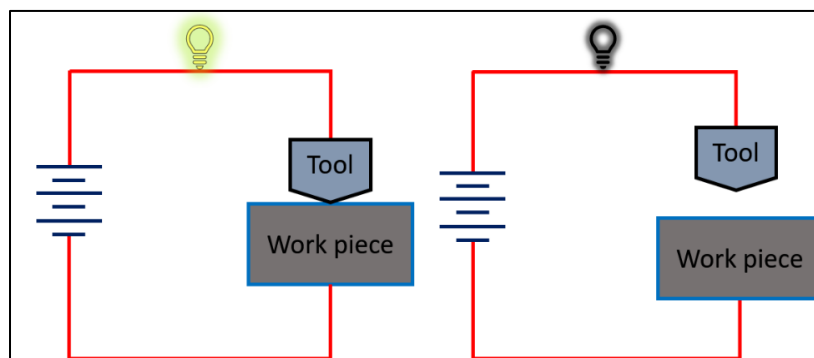


Figure 2

To improve the detection of tool failure, we can add an additional component to the circuit. An open wire will be attached just beside the tool, as it cannot touch the tool and can be a little shorter than the tool as per shown in figure 3. If the tool breaks, the wire will touch the workpiece and the server will detect it as above. This will work in certain conditions like surface finishing step.

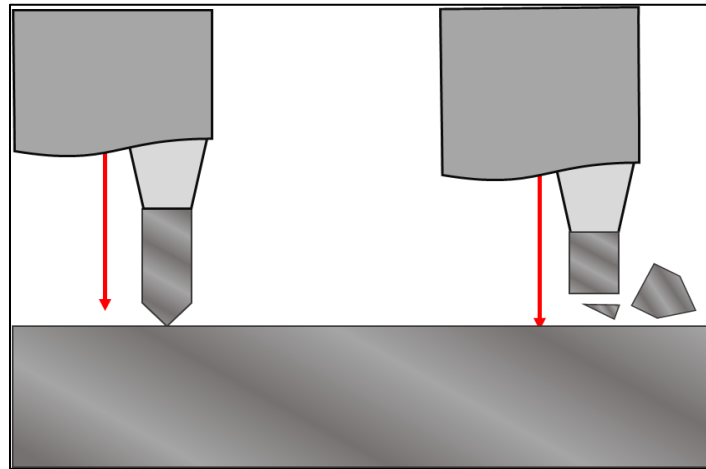


Figure 3

The devices discussed above are both conventional and inexpensive and take up minimal space, so they can be easily attached to machine parts. They can withstand harsh environments and most of them use small batteries as a power source. Their results are immediate and reliable

Product Quality Grading:

By inspecting product quality at regular intervals, we can see if the machine needs maintenance or needs parts to be changed. We will provide server information on what may be the cause behind a particular type of defect in the product, and what to do in that situation. This will almost fully automate production.

We can directly assess product quality at the end of the manufacturing process through the use of various sensors. We can detect product defects such as edge wear, burns, surface humps or scratches in the metal product, which can be caused by excessive clamping force or loosed grip of the spindle, vibration of the tool due to high RPMs or overheating^{[10][12]}.



Image taken from
<https://waykenrm.com/>

For cylindrical products, we can scan them using a technique that is similar to their manufacturing by using CNC lathes. We will mount the product on the rotating spindle. Instead of cutting tools, we will place the previously discussed laser mouse sensor. While designing a product with many edges, errors are often found near the edges or other surface features, therefore we will attempt to focus on those locations. We will mount the product on a platform that can rotate in all directions. Then we will use the laser mouse sensor to scan the edges.

For both cases, If there is any significant change in trends within those images that may be a surface defect feature.

Additional Server Functions:

In addition to detecting malfunctions, the server can also calculate how a particular malfunction affects the overall machine health, tool efficiency and product quality.

We can use the data in the server to provide feedback to machine manufacturing companies. This data can help us get better guidance from technical consulting firms. The

server can also assist us in determining what changes we should make to the assembly line to increase production efficiency.

If the statistics of such failures are high, the server will call upon CNC technicians. Further, it will save the data of the type of fixes applied for particular anomalies and what are the causes for a particular malfunction so that it can provide insight to the new interns.

In addition to assisting us with managing the overall CNC machines, the server can also help us manage the maintenance schedules of the individual machines. The server can attempt to synchronize maintenance schedules in order to decrease overall net downtime. It can also remind us to clean the dust and debris from the machine parts at constant intervals.

The server can filter all the information from all the machines for the Administrator of the facility. This can include the status of each machine (whether it is working, under maintenance, or suspended by the server), the work done since the start of the day, and the work rate, temperature, power usage, and active time.

Other Existing solutions :

[Acoustic emission sensor \(AE Sensors\):](#)

When a solid material is deformed it disperses elastic energy in the form of elastic waves, such as sound. Therefore, when the tool breaks it produces a sound, which is detected by the AE sensors. They can detect sounds of frequency 1KHz to 1MHz.

AE sensors are very sensitive to outside noises. This can cause interference with the results we want. It may lead to false alarms.

url: <https://www.mdpi.com/1424-8220/21/24/8431/html>

[Broken tool monitoring by middex electronics:](#)



Image taken from <https://middex.de/>

Middex uses scanning probes to detect broken tools. The scanning probe sweeps toward the tool and detects resistance. If the tool is not broken, it will face some resistance, and a "OK" signal is generated. If the tool is broken, it won't face any resistance, and a "Not OK" signal is generated. These probes are able to tell if the work piece is in the correct position, or not. The probes are just 1.5 centimeters long, so they don't produce any significant interference. This system is cheap and maintenance-free.

url: <https://middex.de/en/productgroup/tool-monitoring>

Sensemore Trigger devices:

Sensemore uses condition-based monitoring methods for CNC machines, which focuses on spindles (as they are the main reason for downtime). It uses trigger devices as monitoring solutions. This trigger device monitors machine vibrations in real-time, and transmits a five volt signal to the receivers. The cloud application analyzes machine performance based on these signals in just five seconds.

url: <https://sensemore.io/condition-monitoring-in-cnc-machines-and-case-study/>

Uptime monitoring with current-transformation sensors:



Current transformers (CT sensors) are sensing devices used to measure AC current. They are miniature transformers that first induce low-amperage current by a high AC current in wires, which they measure and calculate the original current.

$$I_{CT} = (\text{Current Ratio}) \times I_{\text{Original}}$$

In this situation, we can use CT to directly discover if the machine is on/off at a particular moment. Based on that, we can construct a machine uptime graph and find out (production/energy) value.

url: <https://www.biz4intellia.com/documents/machine-uptime-monitoring-casestudy>

The results are often inconsistent in both of the last cases. It is possible that current is flowing through wires but the tool is not moving due to some glitch. In other cases, it is possible that the machine is vibrating caused to the spindle rotation but the tool is not in contact with the workpiece. It will not alert the operator in such cases. It will also be counting this duration as uptime. This will give us erroneous data.

References:

- 1) “CNC Machine: Types, Parts, Advantages, Disadvantages, Applications, and Specifications” - Saswata Bakshi

url: <https://learnmechanical.com/cnc-machine/>

- 2) Piezoelectric Accelerometers Theory und Application

url: <https://www.mmf.de/manual/transducermane>

- 3) “Vibration monitoring of CNC machinery using MEMS sensors” - Grzegorz Wszolek, Piotr Czop, Jakub Słoniewski, Halit Dogrusoz

url: <https://doi.org/10.21595/jve.2019.20788>

- 4) “6 Most Common Issues Related to the Setup and Maintenance of CNC Machines”
by Peter Jacobs

url: <https://www.cmc-consultants.com/blog/6-most-common-issues-related-to-the-setup-and-maintenance-of-cnc-machines>

- 5) “Tool Wear Detection Using Time Series Analysis of Acoustic Emission” - S. Y. Liang, David Alan Dornfeld University of California, Berkeley

url: <https://asmedigitalcollection.asme.org/manufacturingscience/article-abstract/111/3/199/392992/Tool-Wear-Detection-Using-Time-Series-Analysis-of?redirectedFrom=fulltext>

- 6) “Deep Learning for Infrared Thermal Image Based Machine Health Monitoring” - Olivier Janssens, Mia Loccufier, Rik Van de Walle and Sofie Van Hoecke

url: <https://biblio.ugent.be/publication/8559058>

- 7) “Thermal monitoring with infrared sensors” - Alex Desselle

url: <https://www.processingmagazine.com/process-control-automation/instrumentation/article/15587285/thermal-monitoring-with-infrared-sensors>

- 8) “Optical vs. Laser Mouse | Digital Trends” - By Kevin Parrish

url: <https://www.digitaltrends.com/computing/optical-vs-laser-mouse-explanation/>

- 9) “7 Essential Metrology Tools for Modern CNC Machine Shops” - Nik Seyferth

url: <https://blog.eaglegroupmanufacturers.com/precision-machined-parts-measuring-tools-every-cnc-shop-should-have>

- 10) “On-line wear detection of milling tools using a displacement fiber optic sensor” - Salvador Sandoval

url:

https://www.academia.edu/67287374/On_line_wear_detection_of_milling_tools_using_a_displacement_fiber_optic_sensor

- 11) “Surface Defect Analysis”

url: <https://www.autoform.com/en/newsroom/news/surface-defect-analysis/>

- 12) “4 Common Workpiece Defects And Their Causes In CNC Milling” - WAYKEN RAPID MANUFACTURING LIMITED

url: <https://waykenrm.com/blogs/cnc-milling-defects-and-solutions/>